Lesson Study: The Impact on Teachers' Knowledge for Teaching Mathematics

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Rationale for the Study

Educational standards suggest that students should engage in complex problems that give rise to comprehensive mathematical understanding (National Council of Teachers of Mathematics 2000). Consequently, many teachers will have to shift their pedagogy of memorization, repetition, and recitation of correct answers to developing their students' reasoning and communication skills by actively engaging their students (Smith 2001). In the USA, professional development is often used to help teachers with pedagogical decisions and strategies for effective instruction as well as helping teachers understand the mathematics they teach. The most commonly used forms of professional development include short sessions at meetings, one-to-two day school-based workshops on specific topics, or two-to-three-week grant-supported workshops in the summer. However, another form of professional development occurring in the USA, on a much smaller scale, is lesson study. This study examined whether participating in lesson study as a form of professional development provides opportunities for teachers to improve their knowledge of teaching mathematics.

Much of education reform literature suggests that knowledge for teaching mathematics is essential to learning how to teach subject matter in order for students to understand it (Ma 1999; Smith et al. 2005; Hill et al. 2005). Conventional wisdom asserts, "You cannot teach what you don't know" (National Research Council 2001, p. 373). According to the National Research Council, an academically rich environment begins with teachers who are knowledgeable in mathematics, knowledgeable of students, and knowledgeable of instructional strategies. Knowledge of subject matter with an understanding of instruction results in a highly effective teacher (Phillips 2003; Hill et al. 2005). Research indicates that many US teachers do not possess a deep understanding of mathematics (Mewborn 2003; Ma 1999; National Research Council 2001) and evidence suggests that teachers, particularly at the elementary and

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middle school grades, often have limited content knowledge (Smith 2001). Therefore, this study examined whether or not participation in lesson study would provide opportunities for teachers to improve their knowledge of teaching mathematics.

Context of the Study

Lesson study as defined by Lewis (2002) is a teacher-led instructional improvement cycle in which teachers work collaboratively to: formulate goals for student learning, plan a lesson, teach and/or observe the lesson, reflect on the gathered evidence, revise the lesson for improvement, and reteach the revised lesson (see Chap. 1 Murata). Through the use of lesson study, teachers have a means for planning, observing, and conferring with others.

Twenty-four mathematics teachers, from seven middle schools in a large urban school district, participated in an initial six-hour summer professional development session about lesson study with the goal to plan and implement a lesson study cycle by the end of the calendar year. Participants began by identifying a research theme/mission statement based on the qualities they would like their students to have in five years from now. This is an important first step because the theme should influence the planning of the research lesson. For example, if teachers want their students to be skilled problem solvers and communicators, then the lesson plan should support a discovery, trial and error approach versus direct instruction to become problem solvers. In addition, the plan should allow students to collaborate with peers as a way to develop communication skills. Next, school groups analyzed district curriculum expectations, district test results, and state assessment results in order to identify areas of need in mathematics. Each school group shared results with all participants in order to examine commonalities and differences in students' mathematical understandings for each of the seven schools. Then, each school group selected a content topic to address using the districts' scope and sequence for the second nine-week grading period as a guide. Participants regrouped themselves based on the topics chosen to be addressed in the research lessons with some teachers working outside of their school groups. Teachers also considered their greatest interest to learn and focus on teaching a lesson in this area. Five groups were formed consisting of four to five middle school mathematics teachers with some being from the same school while other groups were a combination of schools. Table 1 describes the demographics for each group.

The day continued with teachers gathering and studying resources on their identified content focus through the use of the internet, district textbooks and curriculum documents, standards-based curriculum resources, and other supporting elements provided by the researchers. Teachers were asked to focus on supporting skills needed to understand the content focus and the most effective sequencing of content topics. In addition, teachers were to assess their own understanding of the topic through discussion with their groups as they gathered information.

Next, the participating mathematics teachers were introduced to the history, goals, and procedures of lesson study. Participants viewed and reflected on a video

Table 1 Description of lesson study groups

Lesson study groups	Number of teachers in each group	Schools represented in each group	Content topic taught	Grade level
Group 1	4	1	Measurement	8th grade
Group 2	4	2	Proportional reasoning	8th grade
Group 3	6	2	Introduce proportional reasoning and scale factors	6th grade
Group 4	5	1	Theoretical and experimental probability	7th grade
Group 5	5	1	Area of similar figures	7th grade

of teachers who had participated in lesson study in order to see all phases of the lesson study cycle. Finally, each group was assigned a facilitator from a higher education institution. The higher education faculty member, whose expertise was in mathematics education, served as the facilitator when the groups met to continue planning their research lesson, and was available to answer questions when they arose. The facilitator was not to interfere with the direction of the research lesson. Groups concluded the initial meeting day by selecting a date for a two hour planning session to work on their research lesson.

Within three weeks following the initial six-hour professional development session, each group met for a two-hour planning session with their assigned facilitator and began working on their research lesson. During the planning session, the teachers completed a plan for the research lesson that included the following elements: the aim of the lesson (research theme/goal and the objective), the learning process for the lesson, the evaluation for the lesson, and copies of lesson materials (Lewis 2002).

The lesson plan consisted of three columns. The first column addressed the sequence of the lesson, problems to be posed, questions to be asked, and activities to be addressed. The second column consisted of anticipated students' questions and responses during various parts of the lesson. The third column was for specific aspects the lesson study team wanted observers to notice during the research lesson. In addition, the five groups determined which group member would voluntarily teach the research lesson. At the conclusion of the session, group members who would observe during the research lesson determined their observation roles and reviewed the observation procedures.

Observation roles consisted of a single observer recording comments and actions from a specific group of students. It should be noted that most lesson study teams had students work in collaborative groups with each group being assigned an observer. Additional observation roles consisted of recording all comments and questions asked by the teacher volunteer to implement the research lesson and an observer to randomly float around the room to the various student groups. Observers were also reminded not to interfere with the research lesson by talking with students and to record as much detail as possible for their observation focus.

On the day in which the research lesson was to be conducted, the volunteer teacher taught the lesson while team members and invited guests, such as the principal,

wrote field notes regarding lesson implementation and student understanding. Following the research lesson, a two-hour reflection session on the research lesson was held. During the reflection session, the teacher who taught the lesson spoke first, reflecting on the lesson implementation, noting what went well, and on any difficulties in the lesson before others shared their reflections. Next, members who assisted in planning the lesson shared their observation notes reflecting on the goals for the students and the design of the research lesson, comparing and contrasting what was planned and what was observed. The discussion focused on the specific notes collected by each observer. Observation notes consisted of students and teacher comments and questions during the lesson as well as observation notes on the use of manipulatives and students' work. The group facilitator then provided feedback and shared in the discussion.

All participating groups were able to implement the research lessons by mid-December. In addition, the groups were able to modify the research lessons based on feedback during the reflection sessions and reteach the lessons. However, the reteaching of the lessons occurred in each individual teacher's classroom without observers due to limited resources for substitute teachers to cover classes for a second time. In early February, the five lesson study groups returned for a two-hour debriefing on their experiences and began plans for a second cycle of lesson study.

Analyzing the Impact of Lesson Study on Teachers' Knowledge

The researchers gathered data from the following sources to examine the impact participating in lesson study had on teachers' knowledge for teaching mathematics. These included: (a) transcripts from audio-recorded planning sessions, (b) research lesson plans, (c) transcripts from research lesson observation recording sheets, (d) transcripts from audio- and video-recorded reflection sessions of the participating teachers, and (e) teacher participant questionnaires. The analysis occurred in four stages. The first stage consisted of transcribing and verifying all records collected during the planning and reflection sessions as well as the research lesson observations. In the second stage two researchers independently hand coded the transcripts based on broad categories aligned with the research question such as "instructional practices" and "content knowledge." Third, the researchers met to discuss and verify the coding as a means to assure accuracy of the findings. The use of a computer software program, *N6* (Richards 2002), was used to code the emerging categories that emanated from the research questions. As patterns emerged, axial coding was used to identify subcategories. The fourth and final stage consisted of the researchers using a constant comparative analysis involving the multiple lesson study groups. This analysis consisted of both within- and across-group comparisons. For the within-group analysis, each group was first treated as a comprehensive study in and of itself. Once the analysis of each group was completed, a cross-group analysis was completed in order to develop more sophisticated descriptions and more powerful explanations (Merriam 1998).

What the Analysis Revealed

Analysis showed that particular factors of the lesson study cycle provided greater opportunity for teachers to increase their knowledge for teaching mathematics. These factors will be referred to as "windows of opportunity." One factor that impacted the development of teaching mathematics was whether or not the teachers implemented an existing lesson with little or no changes compared to creating or making major modifications to a task. A second factor that provided an opportunity to observe evidence of knowledge in teaching mathematics was when a group was able to anticipate students' questions/responses in the lesson plan (see Figure 1). A third factor which provided an opportunity to develop knowledge was when teachers took the time to discuss the content and not just the implementation of the lesson.

In the following discussion we will show the impact participation in lesson study had on the participating teachers. This will be supported through an analysis of statements by the participants throughout the planning and reflection sessions, the research lesson observations, and the lesson plans.

During the lesson study cycle, three windows of opportunity emerged and showed the potential for teachers to increase their knowledge for teaching mathematics. The following discussion will focus around these windows and how each group of teachers reacted to the opportunities. One factor included in the windows of opportunity is the lesson plan or task to be implemented. A second factor is the discussions teachers' had while planning the lessons. The third factor is the teachers' levels of anticipating students' questions and responses. We will begin by discussing the first two factors simultaneously.

Lesson Plans and Discussions

Teachers in groups 2, 3, and 4 showed an increase in their knowledge for teaching mathematics with the lesson task and discussions being contributing factors. Participants in groups 2 and 3 took an existing lesson plan and made significant modifications to the tasks, whereas group 4 created a new lesson task to be implemented.

During the initial planning, the teachers from group 2 decided to use an existing lesson on proportions, but made major changes in order to make mathematical and real world connections in addition to promoting student interest. For instance, teachers chose real world objects such as a cardboard box and a television to compare, in order to determine whether or not they were proportional. Teachers also spent significant time discussing their understanding of ratios and proportions. For example, one teacher asked, "What is the difference between a fraction and a ratio, and does it matter?" Rich questions and discussions such as this supported the teachers' opportunity to grow in their mathematical knowledge. By modifying the lesson plan, teachers had valuable discussions that allowed the individual knowledge of content and students to be expanded by the collective knowledge of the group.

Lesson Plan

Names:
Middle School: Grade:
Topic of the Lesson:
The Unit:
Research Theme (or "Main Aim") of Lesson Study:

Purpose (Goals/Objective):

Plan for the Research Lesson

Lesson Sequence (Questions, problems, and activities posed by the teacher)	Anticipated Student Questions/Responses	Points for Observers to Notice

Summary:
In Class Evaluation/Assessment:
Materials:
Extensions:

Fig. 1 Lesson plan format based on Lewis 2002

Teachers in group 3 also invested a significant amount of time and effort in creating a lesson that would allow students to conceptually understand the meaning of proportional reasoning through a discovery approach. Teachers decided to present a vignette where students would have to determine the height of their assigned "monster" based on a footprint and the use of nontraditional measuring tools. Teachers were aware of the development of their own mathematical knowledge by planning a discovery lesson. For example, one teacher commented, "By developing a prob-

lem for the students to solve, we were able to discuss what information the students would need, which ultimately strengthened my own understanding."

Results also indicated an opportunity to develop teachers' knowledge through the discussion of topics taught at each grade level and the instructional strategies used to teach such skills. For example, proportions were introduced at the 6th grade, and the teacher taught the "butterfly" method. However, the 7th-grade teacher explained his issues and concerns about using such a method to teach proportions, which resulted in the 6th-grade teacher increasing her own understanding of proportions. In fact, during the reflection session, this 6th-grade teacher said, "I do admit that having 7th- and 8th-grade teachers in the planning did help me see the vertical planning of ratios and proportions through the middle school years, and what I needed to know about proportions and how to teach it."

When designing the research lesson, the teachers from group 4 decided to choose an example to illustrate probability and fairness. The teachers decided to pose the question: Is *Rock, Paper, Scissors* a fair game? The teachers knew that their 7th-grade students often played this game to settle arguments, and students would be interested to find out if their opinions were supported mathematically. The facilitator later reflected that during the planning session, "This group seemed to really focus on probability and within probability, the fairness of a game. What fairness means and how to determine if it is present." The facilitator went on to say that in his expert opinion, teachers' mathematical knowledge is deepened when they see new and deeper connections regarding a topic in relation to the rest of the content, and these teachers illustrated that by their focus on the idea of fairness and the creation of a new lesson to address this idea.

While participating in lesson-study-provided opportunities to observe teachers' knowledge in teaching mathematics, groups 1 and 5 did not allow for this opportunity to be developed. Three factors may have contributed to this: (1) the use of an existing lesson with no modifications, (2) more focus on the implementation of the lesson and not the concepts, and (3) limited anticipation of students' questions. We will discuss the first two factors simultaneously.

Teachers from group 1 decided to utilize an existing lesson with no modifications and their focus became implementation and not the content of the lesson. For example, the teachers wanted students to increase their estimating and measuring skills so they used an established lesson activity where students would work in groups to estimate one person's facial features and then illustrate that face using accurate measurements. During the planning session, the teachers focused on the needed materials, the roles of the students, and who would teach the lesson with limited discussion on the content. The assigned facilitator attempted to guide the group by asking questions such as: "What do you want your students to understand?" "What do you want your students to be able to do?" "How will you know they can measure accurately?" "How will you know if the students understood?" One teacher responded, "We will look at the papers. If the nose is 30 cm then they are wrong." Another teacher said, "Maybe off two-three centimeters." The facilitator responded, "With a nose, that's a lot." Instead of continuing with a discussion about measurement, the teacher returned to discussing the implementation of the

lesson. Another example occurred during the reflection session when the facilitator again questioned how the teachers would know when students' understood the content and one teacher responded, "A competition could be formed of who could draw the best; make the better features and so forth; which drawing came out the best." The teacher's focus was not on mathematical content but rather on nonmathematical areas such as artistic concerns and the ability to draw.

Teachers in group 5 did not benefit from the opportunities provided by lesson study to develop mathematical knowledge as a result of three contributing factors. First, only one teacher and the assistant principal attended the initial six-hour professional development session on lesson study. In addition, the assistant principal ended up writing the research lesson plan with limited input from the teachers. The teachers spent the entire planning session deciding on the topic of similar figures and sharing how they had taught the concept in the past. Finally, the teacher who volunteered to teach the research lesson did not follow the lesson plan but instead taught the topic as she previously had with her own students. Therefore, this group did not necessarily follow the lesson study cycle and this called into question the fidelity of implementation of lesson study.

The third factor in the windows of opportunity is the level in which teachers took the time to discuss and anticipate students' questions/responses. Again, teachers from groups 2, 3, and 4 showed an increase in their knowledge for teaching mathematics by anticipating students' questions and responses regarding the lesson.

Level of Anticipated Students' Questions/Responses

Teachers in group 2 spent a significant amount of time discussing and predicting students' questions and responses. There was one predicted question and seven anticipated responses. The predicted question pertained to mechanics such as, "What if only a little of a paper clip is left?" However, the anticipated student responses focused on conceptual understanding. For example, "Students should respond by saying that the taller the person, the larger his/her foot should be." Another prediction was, "Students may not understand which two columns [to use] from the chart to graph. They also may count boxes on the graph instead of lines and try to make a bar graph." The teachers also predicted, "Students will notice that the graph is [a] straight line and hopefully understand, if it is linear then it is proportional." Again, opportunities to observe teachers' knowledge of students and mathematics was provided through the discussion.

The teachers from group 3 put considerable thought into predicting students' questions. It should be noted that the teachers accurately predicted the student questions. For example, the teachers predicted numerous student questions regarding how to measure objects if not given standard measuring tools such as a ruler. "How do we figure this out?" "How am I supposed to figure this out without a ruler?" Analysis of the reflection transcripts from the research lesson reflected that students did indeed ask questions such as "How do we know if we are right without a ruler?"

Again, by having teachers predict students' questions and responses, this element encouraged teachers to think in terms of the students, which supports a better understanding of their own knowledge of both mathematics and students. One teacher even commented, "Trying to think like the students would think during the lesson made me have to look at the lesson as if I was learning it for the first time and even improved my own understanding."

On the lesson plan, teachers from group 4 also spent a significant amount of time discussing areas students may struggle with and were able to predict students' questions and responses that arose during the lesson task. For example, the teachers predicted that students would define fair as a 50/50 chance and would struggle with explaining fair if more than two people were involved. In addition, teach-

Table 2 Key factors of lesson study groups

Lesson study groups	Lesson plan/task	Level of anticipated students' questions/responses	Lesson-planning discussions
Group 1	Teachers used an existing lesson plan with no modifications from the original activity	Teachers listed five anticipated student questions that mainly addressed how to read a ruler. No student responses listed	Teachers focused on the implementation of the lesson and not on the content of the lesson
Group 2	Teachers used an existing lesson plan with major modifications connected to real world applications	Teachers listed one anticipated student question that pertained to instructions. Teachers listed seven responses that addressed students' level of conceptual understanding	Teachers focused on the implementation of the lesson and on the content of the lesson
Group 3	Teachers used an existing lesson plan with major modifications based on a discovery lesson	Teachers listed eight anticipated student questions that addressed areas students would struggle with based on a discovery approach	Teachers focused on the implementation of the lesson and on the content of the lesson
Group 4	Teachers created the lesson plan	Teachers listed two anticipated student questions that addressed rules for the game. Teachers listed five student responses that addressed students' level of conceptual understanding	Teachers focused on the implementation of the lesson and on the content of the lesson
Group 5	Lesson plan was created by the assistant principal with little teacher input	Teachers listed no anticipated student questions. Teachers listed three student responses that consisted of predicted students' answers to questions	Teachers focused on the implementation of the lesson and not on the content of the lesson

ers felt students could easily determine through tree diagrams whether or not the *Rock, Paper, Scissors* game was fair, but would struggle if the scenario changed. Instead of two people using either the rock, paper, or scissors symbol, would one player have an advantage if he/she never used the scissor symbol? Teachers were able to again anticipate what their students would do with the problem and their questions.

Unfortunately, teachers from groups 1 and 5 did not spend significant time discussing and predicting students' questions and responses to the lesson plan, and missed the third factor in the windows of opportunity to improve their knowledge for teaching mathematics. The teachers in group 5 did not discuss or write any student predictions and the teachers in group 1 only predicted student questions that addressed how to read a ruler. For example, they predicted, "What if the ruler is between two lines? How big is a centimeter?" The teachers did not discuss student responses or make predictions regarding their thoughts and their mistakes pertaining to conceptual understanding. Table 2 provides an overall summary of the lesson study groups and which factors did or did not improve teachers' knowledge in teaching mathematics.

Implications and Conclusion

Does participation in lesson study provide opportunities to improve the knowledge for teaching mathematics? Analysis suggests out of five lesson study groups, lesson study did provide opportunities for improved teacher knowledge in three of the groups. These groups displayed some common elements during their participation in lesson study that provided these opportunities.

First, all three groups planned research lessons that were either created or based on a previous lesson, but made significant changes in the lesson in order to address students' interests and make connections. On the other hand, the two groups who implemented previously established lessons with little or no modifications did not demonstrate these behaviors. We are not suggesting that teachers' knowledge cannot improve when using an established lesson plan for lesson study, but pointing out that this seemed to be a contributing factor for these groups.

Another common characteristic of the three groups was relatively accurate predictions regarding students' questions and responses. These groups had in-depth comments and questions listed under this particular column on the lesson plan that revealed careful thought. For example, one group predicted students would be able to state, "A fair game is when each person has an equal chance of winning and not just 50/50 always." The other lesson plans anticipated very few student questions and responses and appeared to be limited in their own depth of mathematical understanding and knowledge of students. For example, when estimating and measuring facial features, the teachers listed questions such as "What happens if it's between the lines?"

The third characteristic present in these three groups was the focus on the understanding of the mathematical concept and not only the implementation of the lesson.

Time was spent in their planning sessions talking about and discussing possible activities to help students conceptually understand and make mathematical connections regarding the research lesson focus. Whereas the other two groups focused on the procedural aspects of the lesson such as the location for the lesson to be taught, the grouping of the students, and who was going to do what to prepare for the lesson. While these may be valid areas to address when planning a lesson, they do not necessarily reflect a deep understanding of the knowledge needed for teaching mathematics.

This study was to explore whether participation in lesson study would (1) result in an increase in teachers' mathematical knowledge and (2) improve teachers' knowledge for teaching mathematics. More research is needed to examine the impact lesson study has on teachers' knowledge. However, this study provides insight into potential factors that would help support an increase in teachers' knowledge of teaching mathematics while participating in lesson study.

This study supports recent research by Ball et al. (2008) related to potential elements that increase teachers' knowledge of teaching. Analysis showed that teachers who participated in lesson study had opportunities to develop knowledge by predicting students' responses and questions. In addition, the teachers who discussed the targeted content areas and not just the implementation of the lesson revealed a deeper understanding for teaching mathematics. So does teachers' knowledge of teaching mathematics increase when they focus on anticipating students' questions and responses? Does teachers' mathematical knowledge increase with less focus on the implementation of the lesson and more on the activities and connections in mathematics and the real world? In three out of five lesson study groups, the answer seems to be that lesson study did provide "windows of opportunities" to observe and develop mathematical knowledge for teaching.

It is imperative for teachers to strive for continuous improvement of instructional strategies and knowledge because teachers are the key to students' understanding and achievement in mathematics (Dana and Yendol-Silva 2003) and instructional changes are more likely to occur in sustained efforts and in small incremental steps (Guskey 2000). Lesson study addresses one lesson at a time, but impacts learning and instruction in several aspects. Lesson study allows teachers to view teaching and learning as they occur in the classroom. With time, lesson study has the potential to build learning communities within schools and ultimately result in instructional improvement and increase in teachers' knowledge with focus on the student and the content.

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